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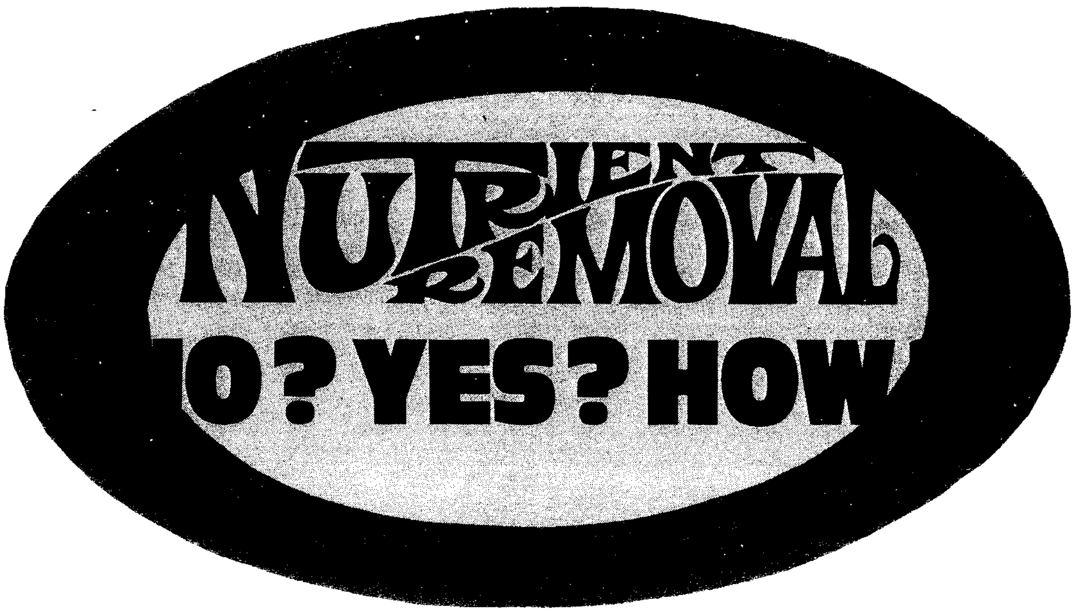

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Is nutrient removal worthwhile?

The answer depends on lake classification conditions, such as input of phosphorus from natural sources, these authors say.

By Roger W. Bachmann and John R. Jones

SHOULD NUTRIENTS be removed from wastewater to prevent eutrophication?

There seems to be no definitive answer.

In some cases nutrient removal can be an important component of the nutrient-reduction program for eutrophication control. In others, where the natural inputs of phosphorus are great, no benefits may be seen from nutrient abatement.

The importance of plant nutrients in determining the quality of lake water has long been recognized. Through a knowledge of quantitative relationships between nutrients and water quality, criteria have been developed to manage lakes by regulating the nutrient concentrations through nutrient input control. The practicality of applying these measures to all water bodies, however, must be evaluated to determine if measurable benefits will be realized.

The most widely used system of lake classification separates lakes into two broad classes on the basis of their nutrient status, oligotrophic for lakes that are nutrient poor and eutrophic for lakes that are nutrient rich. The system is useful because there are other characteristics associated with nutrient status. Because of their low nutrient concentrations, oligotrophic lakes have low populations of plankton algae and generally have clear water.

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Oligotrophic lakes support only small amounts of organic materials that therefore slightly reduce oxygen concentrations upon their decomposition. Eutrophic lakes are characterized by abundant algal growth, poor water transparency, and reductions or depletions of dissolved oxygen in the deeper portions. Because of their greater biological productivity, eutrophic lakes tend to produce larger fish harvests, but not necessarily of the most desirable species. For most uses of water, the quality of oligotrophic lakes is superior to that of eutrophic lakes.

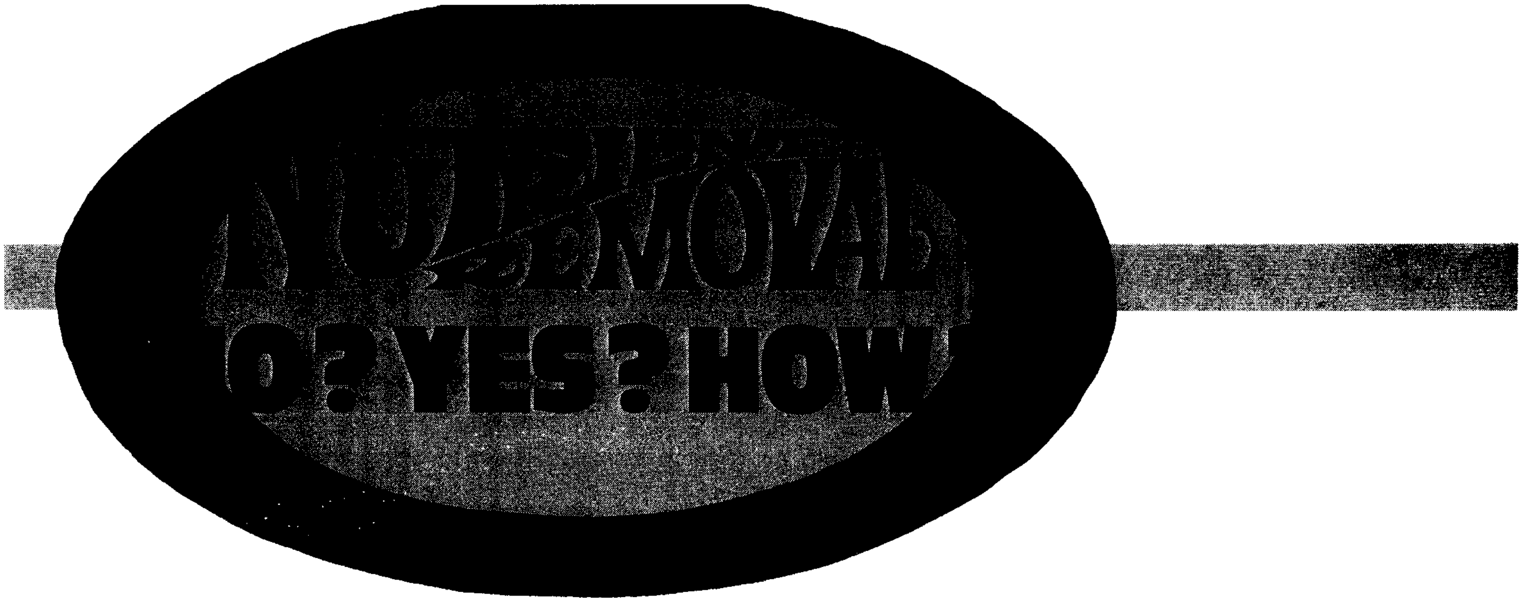
Studies of lake history by use of sediment cores have determined that many lakes are initially oligotrophic and, over periods of many hundreds or thousands of years, became eutrophic, a process termed eutrophication. It also has been learned that eutrophication can be accelerated by the artificial addition of plant nutrients to lakes. This has been done intentionally for many years in intensive fish culture where it is desirable to raise the productivity of fish ponds. It also has been done unintentionally where treated or untreated sewage effluents have been introduced into lakes. In many instances, this has resulted in a rapid acceleration of the eutrophication process, with a marked deterioration in water quality.

Eutrophication can be reversed

There is concern about what might be done to prevent artifical eutrophication and what can be done to renovate lakes in which changes already have taken place. In Lake Washington near Seattle, it was demonstrated that eutrophication could be reversed if the source of the artificial enrichment could be removed. There, it was possible to completely divert the effluents from the lake, resulting in a significant improvement in water quality.

Because nutrient diversion is not always possible, another approach is to remove nutrients from effluents before discharge into receiving waters. This procedure is now being applied to reduce the nutrient inputs to the Great Lakes. These are important bodies of water that have been noted for their high water quality in the past and that should be protected from eutrophication.

If nutrient removal is a worthwhile procedure for the protection of the Great Lakes, should it be applied to all effluents for the protection of water quality in other parts of the country? Should this be a required procedure along with present requirements for primary and secondary treatment? In our opinion, the benefits have to be established for each situation or geographical area first. An initial step would be to determine if nutrient removal would have a significant effect on the receiving bodies of water. Fortunately, quantitative techniques are being developed that enable water



managers to do this in many instances.

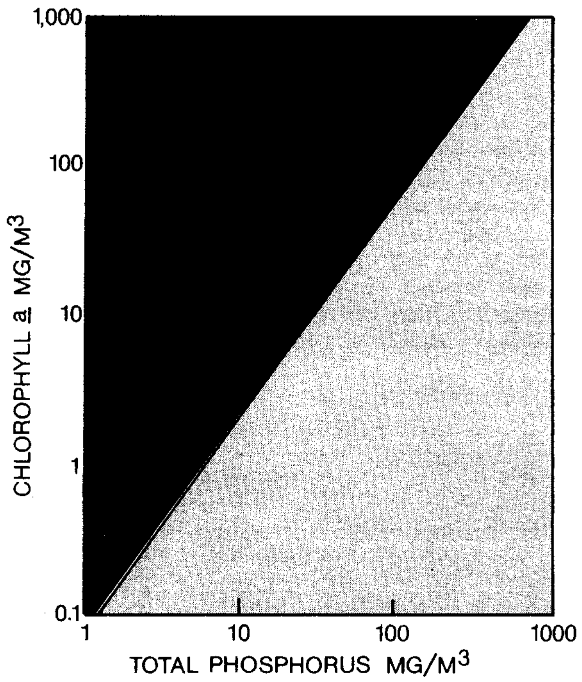
P may be key element

Increasing evidence indicates that phosphorus is the key element in eutrophication control. Not only is it one of the easiest to remove from effluents, but it also is the element most likely to be controlling the density of algal populations in most lakes of the world. Recent research by ourselves and others has shown that there is a strong correlation between the concentration of total phosphorus in lakes and the summer levels of plankton algae as measured by chlorophyll *a* pigments. The relationship is shown in Figure 1 and covers a wide range from unproductive oligotrophic to highly eutrophic lakes. The greater the phosphorus concentration, the greater the level of chlorophyll *a*. Reductions in the concentrations of phosphorus in a lake should lead to a lower algal population. Such a reduction was indeed found in Lake Washington after diversion.

To use this relationship, it is necessary to know what determines the concentration of phosphorus in lakes. We have recently developed a semi-empirical equation for making such a calculation in natural lakes:

$$P = L/(z(0.65 + \rho)) \qquad (1)$$

where P is the concentration of total phosphorus in a lake (mg/m^3), L is the annual phosphorus loading ($mg/m^2/yr$), z is the mean depth of the lake (m), and ρ is the hydrologic flushing rate (yr^{-1}) found by dividing the annual water outflow by the volume of the lake. Other workers have developed equations that produce similar results. The phosphorus concentration is directly proportional to the annual inputs and inversely proportional to the depth of the lake. On the basis of this equation and the



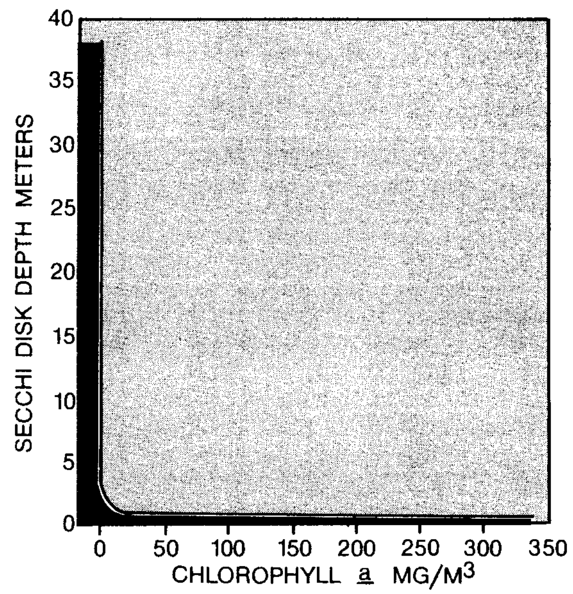


Fig 1: (left) Relationship between total phosphorus concentrations in lakes and summer levels of plankton algae as measured by chlorophyll *a*. **Fig. 2:** Hyperbolic relationship between Secchi disk depth and chlorophyll *a* concentration.

phosphorus-chlorophyll *a* relationship, a reduction in the phosphorus inputs will result in a reduction in the algal population. The magnitude of the reduction in the phosphorus load to a given body of water from a nutrient removal program will depend upon the relative amounts of phosphorus being contributed to the lake from other sources such as surface runoff and rainfall. Field measurements are necessary to develop nutrient budgets for individual bodies of water in order to make that assessment.

Algal levels vs water quality

Although reduction in inputs should reduce algal levels, what does this mean in terms of water quality? One readily perceived attribute of water quality for recreational uses is water transparency. This is commonly measured as the depth at which a white disk (Secchi disk) disappears from view when lowered into a lake. Various workers have found that there is a hyperbolic relationship between the Secchi disk depth and the chlorophyll *a* concentration, particularly for lakes without stained waters or containing high concentrations of suspended inorganic particles. A representative curve is shown in Figure 2. There is a sharp break in the curve at about 10 mg/m^3. Unless chlorophyll levels are reduced below that level, there will be little observable improvement in transparency, although there may be other limnological benefits such as a reduction in the magnitude of oxygen depletions. The general public will not perceive changes until chlorophyll levels drop below 10 mg/m^3. Phosphorus levels should be less than about 25 mg/m^3 to reach this level.

The model presented provides an objective basis for evaluating the potential benefits of nutrient removal in a particular situation. In areas of the country with small natural loads of phosphorus to lakes, the calculation might be expected to show the potential for substantial improvements in lake conditions. When we examine Iowa lakes, few benefits are predicted because of the relatively heavy loadings from nonpoint sources. For example, in a study of 34 streams in northwestern Iowa, we found average total phosphorus concentrations of 0.4 mg/l, with an average output of 0.35 kg/ha/year of phosphorus. These were in small agricultural watersheds with no cities or towns. The results agree with measurements made on the Des Moines River over a period of years that showed a loss rate of 0.38 kg/ha/year. In that case, there were several small towns in the watershed. A typical lake in this region might have a ratio of watershed to lake area of 8.0 and a mean depth of three meters. The average annual runoff would be 13 cm. This would give an annual loading of 280 mg/m^2 and a flushing rate of 0.35/year. From equation 1, this would yield a calculated phosphorus level of 93 mg/m^3 and a chlorophyll *a* concentration of 61 mg/m^3. This clearly is going to result in a eutrophic lake with a low transparency value. This explains why Iowa lakes in general are eutrophic and illustrates why a statewide program of nutrient removal would not change their general character, although nutrient removal at a few key points might be of value for the protection of some individual lakes. The model can be used to make this determination.

Rivers more complex

Although we have methods for predicting the response of lakes to nutrient removal, there is very little basis for making such a decision for rivers. They are more complex systems than standing waters, and water and algal populations move through them continuously. Researchers on eutrophication have tended to neglect them in preference to the simpler lake systems. For this reason, we will confine our remarks to Iowa rivers where we have some first-hand experience.

It already has been noted that Iowa rivers carry high concentrations of total phosphorus. They are also high in organic nitrogen and have high densities of planktonic algae. A recent study of central Iowa rivers showed average levels of 55 mg/m^3 of chlorophyll *a* and 24,500 cells/ml. There is evidence that indicates that these populations are not nutrient-limited. There is a lack of correlation between algal densities and the concentrations of nutrient ions. When river water samples are brought into the laboratory and incubated in the light, there are significant increases in algal chlorophylls, indicating that abundant nutrients are present in the water. In addition, statistical analyses of variations in algal densities in several rivers show that physical factors, such as volume of flow, water temperature, and size of drainage area, account for 50% of the variance in algal densities between samples. It seems that these rivers are nutrient-rich media and that the algal populations pass through them before they have a chance to exhaust the nutrient elements and attain maximum biomass.

On the basis of these observations, it seems that large reductions in nutrient concentrations would be necessary before algal populations would be reduced through nutrient limitation. These are unlikely to be achieved through nutrient removal in this state. The Iowa Department of Environmental Quality has recently estimated that nonpoint sources account for from 70% to 96% of the phosphorus loading in the major river systems of the state. At this point, we conclude that there is no basis for recommending nutrient removal for the protection of rivers within the state of Iowa. There could be some benefit outside the state inasmuch as water passes to the Missouri and Mississippi rivers, although we have no way to calculate what the benefit might be. Nutrient removal might be of value to rivers in other parts of the country. □□